(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
22 May 2003 (22.05.2003)

PCT

(10) International Publication Number
WO 03/043172 A1

(51) International Patent Classification[7]: H02P 1/46, 5/28, 7/36

(21) International Application Number: PCT/US02/36382

(22) International Filing Date: 12 November 2002 (12.11.2002)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/337,506 12 November 2001 (12.11.2001) US

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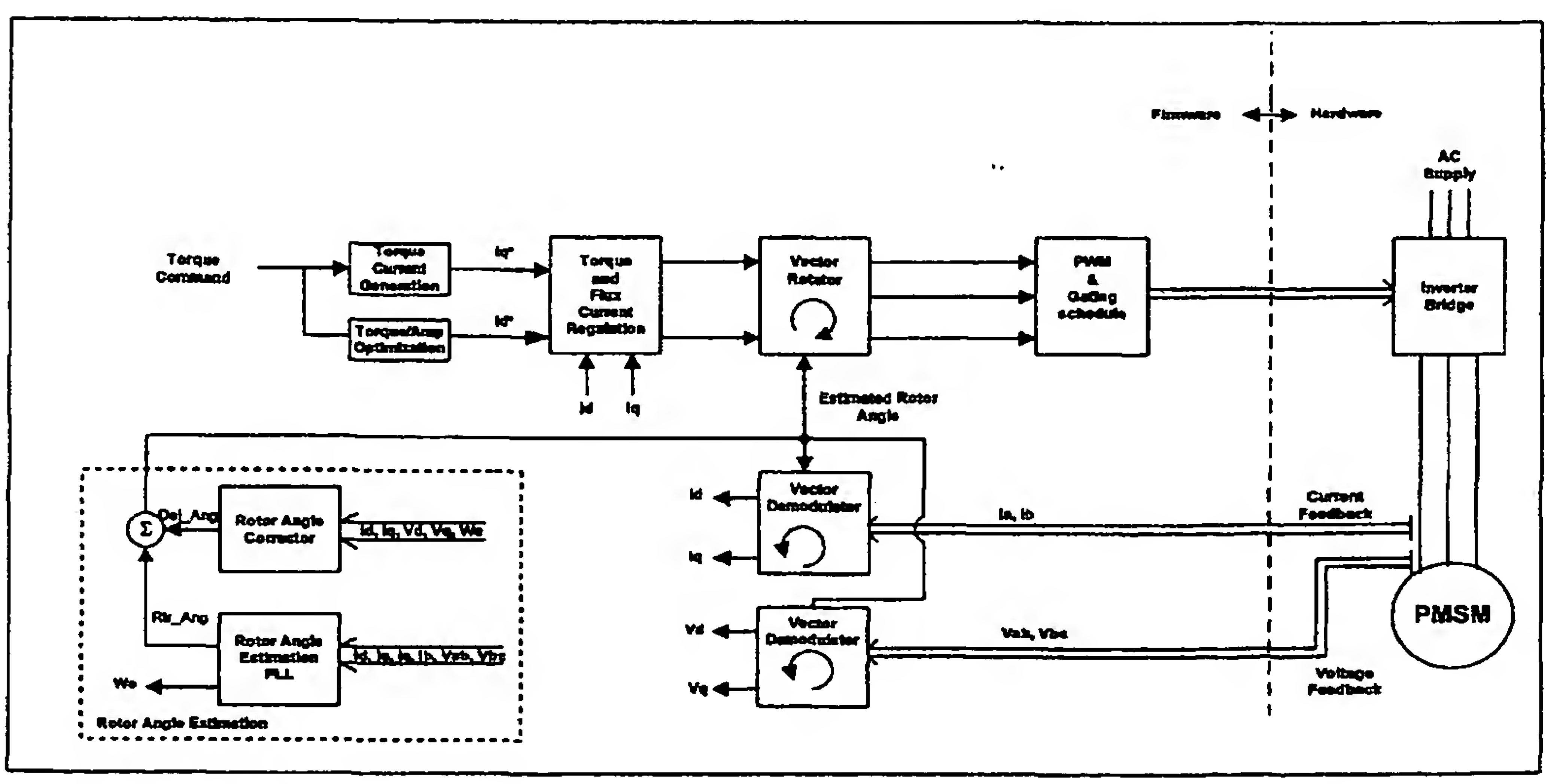
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*
— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: ROTOR ANGLE ESTIMATION FOR PERMANENT MAGNET SYNCHRONOUS MOTOR DRIVE



(57) Abstract: A method of determining a rotor angle in a drive control for a motor, comprising the steps of (a) determining a rotor magnetic flux in the motor; (b) estimating the rotor angle on the basis of the rotor magnetic flux; and (c) correcting the estimated rotor angle on the basis of reactive power input to the motor. Step (a) may include the step of non-ideal integration of stator voltage and current values.Step (b) may include the step of correcting phase errors caused by said non-ideal integration via a PLL circuit with phase compensation (F). Step (c) may include the steps of (1) calculating a first reactive power input value as 1.5*We*(C_Lq *I*I) and a second reactive power input value as 1.5*(Vq*id-Vd*iq); (2) determining a difference between said first and second reactive power input values; and (3) applying said difference to the rotor angle estimated in step (b) to obtain a corrected rotor angle.

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ROTOR ANGLE ESTIMATION FOR PERMANENT MAGNET SYNCHRONOUS MOTOR DRIVE

CROSS-REFERENCE TO RELATED APPLICATION

This application is based on and claims priority of U.S. Provisional Patent Application Serial No. 60/337,506 filed November 12, 2001, the disclosures of which are incorporated by reference.

FIELD OF THE INVENTION

[0001] This invention relates to controls for motor drives and more specifically relates to a technique for the estimation of rotor angle in a permanent magnet synchronous motor drive.

BACKGROUND OF THE INVENTION

[0002] Rotor position information is in general required for the stable operation of permanent magnet AC motors having sinusoidal current excitation. Continuous rotor position has been obtained in the past from encoders mounted on the motor shaft or indirectly through estimation algorithms based on voltage and current feedback. The latter is preferred because it results in lower system and operating cost.

[0003] However, most passive rotor estimation schemes (based on measured voltage and current) are complex and require precise knowledge of the motor parameters such as resistance and inductance. However, these parameters, particularly the stator resistance, change widely with temperature. This leads to inaccuracy in rotor angle estimation and results in control stability problems, reduced torque per ampere capability and degradation of motor operating efficiency.

[0004] It would therefore be desirable to produce a rotor angle estimation scheme which provides maximum torque per ampere performance

without requiring accurate knowledge of the stator resistance or other motor parameters.

BRIEF SUMMARY OF THE INVENTION

[0005] The invention provides a novel method of estimating rotor angle information for the control of a permanent magnet AC motor having sinusoidal back EMF.

[0006] The rotor angle is estimated via a phase-lock loop (with phase error compensation) which receives an estimate of the rotor magnetic flux. The rotor magnetic flux is obtained from the stator voltage (actual voltage or command voltage), current, resistance and inductance.

[0007] Then, the rotor angle estimation error (stator resistance change due to temperature) is removed by using a novel angle error corrector. This corrector is based on reactive power compensation and is insensitive to resistance change. Furthermore, only one inductance parameter is required for the angle corrector's reference model.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Figure 1 is a block diagram showing a PMSM control system which includes an embodiment of the invention.

[0009] Figure 2 is a more detailed block diagram showing the rotor angle estimator of Figure 1.

[0010] Figure 3 is a circuit diagram of a rotor magnetic flux estimator associated with the diagram of Figure 2.

[0011] Figure 4 is a more detailed diagram showing the rotor angle corrector of Figure 1.

[0012] Figure 5 is a graph showing a relationship between reactive power error vs. rotor angle error, per unitized to the motor rated power.

DETAILED DESCRIPTION OF THE DRAWINGS

[0013] The present invention as described in Figures 1 to 5 is related to a motor control algorithm that is implemented in firmware. However, the scope of the invention includes implementations in any combination of hardware, firmware and software that would have been within the ordinary level of skill in the art.

[0014] A block diagram of the control method is shown in Figure 1. The d-axis is the orientation which aligns with the magnetic axis of the rotor (the convention used in the literature).

[0015] The following are the definitions of the quantities listed in Figure 1.

id*	- flux current command
iq*	- torque current command
id	- flux current feedback
iq	- torque current feedback
ia, ib	- phase currents
Rtr_Ang	- estimated rotor angle
C_Rs	- stator per phase resistance
Del_Ang	- compensation angle from angle corrector
Vab, Vbc	- line voltage feedbacks
Vd	- flux-axis voltage feedback
Vq	- torque-axis voltage feedback
We	- inverter fundamental frequency

[0016] The rotor angle estimation block of Fig. 1 is shown in detail in Figure 2. The inputs Flx_A and Flx_B are rotor magnetic fluxes which are obtained by non-ideal integration of motor back emf which is formed by the stator current, voltage, resistance and inductance as shown in Figure 3. In the Figures, Tf represents the time constant of the non-ideal integrator.

[0017] It will be noted that the inputs (V_A, V_B, I_A and I_B) to the flux estimator of Figure 3 are simply the 3-phase (ia, ib, Vab, Vbc) to 2-phase transformed signals.

[0018] The rotor angle estimator (Fig. 2) utilizes a novel flux phase lock loop system. A frequency feedforward circuit F compensates for phase errors due to the non-ideal integration of stator voltages which was used in Fig. 3 to obtain the flux. The phase error generated by the non-ideal integration is fully compensated for in the circuit F.

[0019] Then, the estimation error due to resistance is compensated by a rotor angle corrector system which is described below in connection with Fig. 4.

[0020] The rotor angle corrector circuit of Figure 1 is shown in detail in Figure 4. When the estimated rotor angle (Figure 1) matches up with the actual rotor angle, a reference value for the reactive power (Q) input to the motor is equal to:

1.5*We*(C_Lq*I*I+Flx_M*id+(C_Ld-C_Lq)*id*id)

[0021] Note, however, that for a permanent magnet surface mount (PMSM) motor, the airgap reluctance is identical in the d-axis and the q-axis. Thus, id=0 and Ld=Lq. Therefore, the above equation for reference reactive power can be reduced to:

[0022] 1.5*We*(C_Lq*I*I)

[0023] The actual motor reactive power (Q), expressed in terms of voltage and current only, is then computed by:

Q=1.5*(Vq*id-Vd*iq).

In the foregoing equations:

C_Ld - d-axis inductance,

C_Lq - q-axis inductance,

I - Stator current magnitude,

Flx_M - Equivalent flux linkage of rotor magnet,

Q - Terminal reactive power, and

We (omega e) - stator fundamental frequency.

[0024] Since C_Ld=C_Lq, the rotor angle correction can be achieved with only one inductance parameter (Lq or Ld). Lq is used in this case. Of course, the invention is adapted for use with other motor types as well, such as interior permanent magnet motors in which Ld is not equal to Lq, as will be appreciated by those having the ordinary level of skill in the art.

[0025] If the estimated rotor angle matches up with the actual rotor angle then the following relationship will be satisfied:

$$(Vq*id - Vd*iq) - We * C\_Lq * I * I = 0$$

[0026] Thus, the reactive power error between Q and (We*C_Lq*I*I) (the vertical axis in Figure 5) can be used to null out any rotor angle error (the horizontal axis in Figure 5), such that the maximum torque per ampere can be maintained, even when there is an error in the resistance parameter used in the magnetic flux estimator (Fig. 3).

[0027] Although the present invention has been described in relation to particular embodiments thereof, many other variations and modifications and other uses will become apparent to those skilled in the art. Therefore, the present invention is not limited by the specific disclosure herein.

I claim:

1. A method of determining a rotor angle in a drive control for a motor, comprising the steps of:

a) determining a rotor magnetic flux in the motor;

b) estimating the rotor angle on the basis of the rotor magnetic flux; and

c) correcting the estimated rotor angle on the basis of reactive power input to the motor.

2. The method of claim 1, wherein step (a) includes the step of non-ideal integration of stator voltage and current values.

3. The method of claim 2, wherein step (b) includes the step of correcting phase errors caused by said non-ideal integration via a PLL circuit with phase compensation (F).

4. The method of claim 1, wherein step (c) includes the steps of:

calculating a first reactive power input value as 1.5*We*(C_Lq *I*I) and a second reactive power input value as 1.5*(Vq*id-Vd*iq);

determining a difference between said first and second reactive power input values; and

applying said difference to the rotor angle estimated in step (b) to obtain a corrected rotor angle.

5. A method of determining a rotor angle in a drive control for a motor, comprising the steps of:

a) determining a rotor magnetic flux in the motor; and

b) estimating the rotor angle on the basis of the rotor magnetic flux;

wherein step (a) includes the step of non-ideal integration of stator voltage and current values.

6. The method of claim 5, wherein step (b) includes the step of correcting phase errors caused by said non-ideal integration via a PLL circuit with phase compensation (F).

7. A method of determining a rotor angle in a drive control for a motor, comprising the steps of:

estimating a rotor angle; and

correcting the estimated rotor angle on the basis of reactive power input to the motor.

8. The method of claim 7, wherein said correcting step includes the steps of:

calculating a first reactive power input value as We*(C_Lq *I*I) and a second reactive power input value as (Vq*id-Vd*iq);

determining a difference between said first and second reactive power input values; and

applying said difference to the estimated rotor angle to obtain a corrected rotor angle.

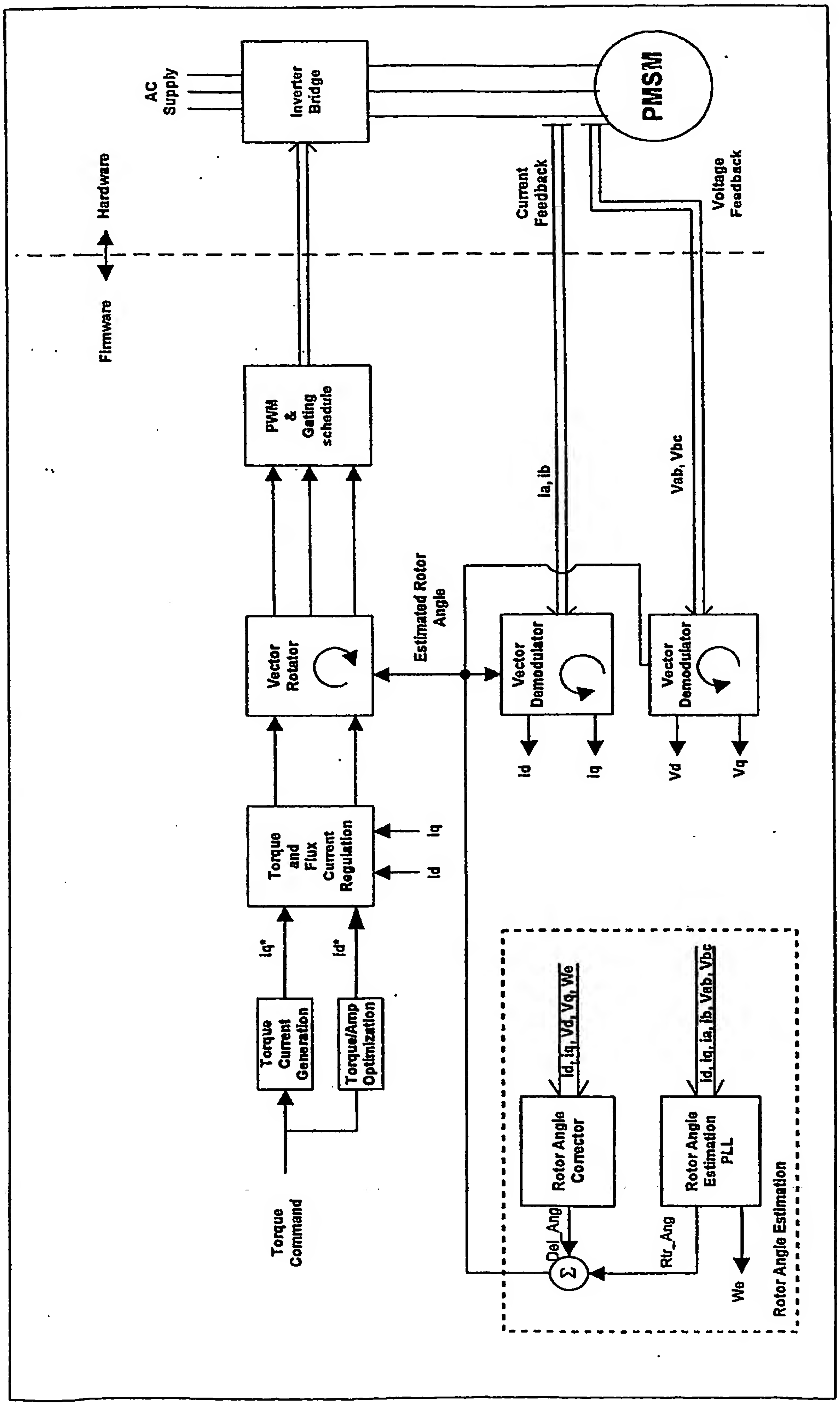

AC Supply
Inverter Bridge
PMSM
Hardware
Firmware
Current Feedback
Voltage Feedback
PWM & Gating schedule
Ia, Ib
Vab, Vbc
Estimated Rotor Angle
Vector Rotator
Vector Demodulator
Vector Demodulator
Id
Iq
Vd
Vq
Torque and Flux Current Regulation
Iq
Id
Iq*
Id*
Torque Current Generation
Torque/Amp Optimization
Torque Command
Id, Iq, Vd, Vq, We
Id, Iq, Ia, Ib, Vab, Vbc
Rotor Angle Corrector
Rotor Angle Estimation PLL
Del_Ang
Rtr_Ang
Σ
We
Rotor Angle Estimation

Fig. 1

Fig. 2 Rotor Angle Estimation

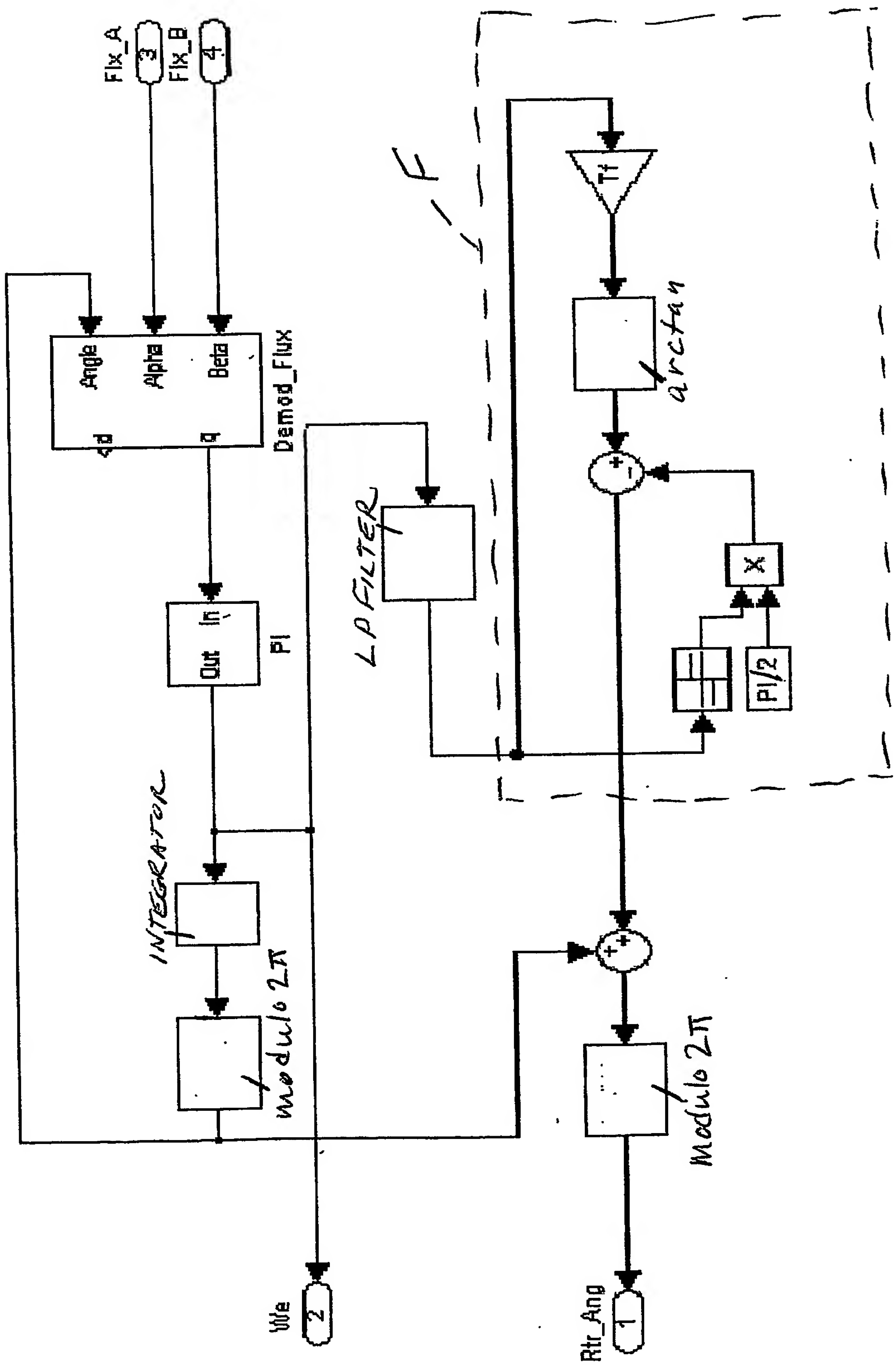
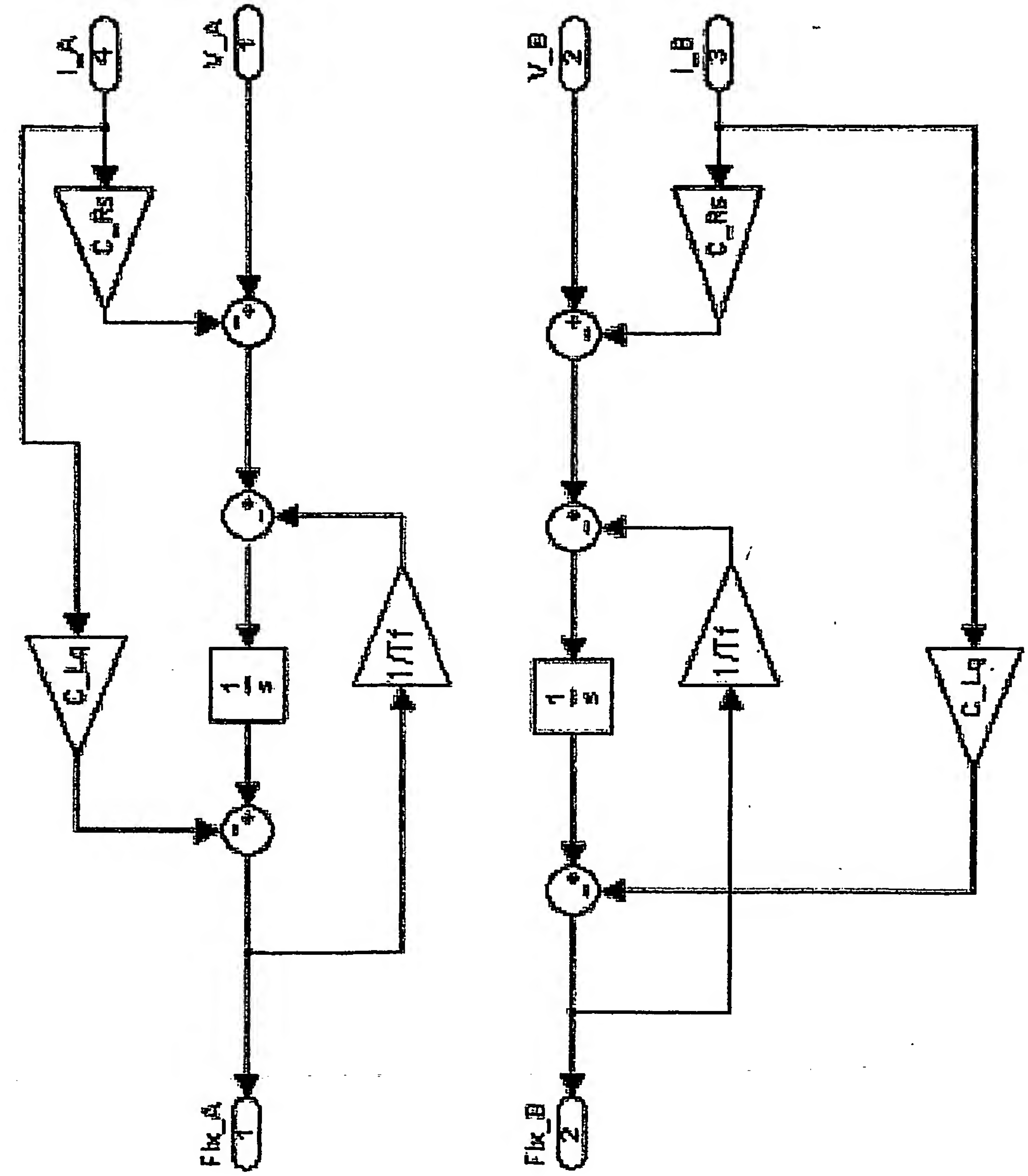


Fig. 3 Magnet Flux Estimation



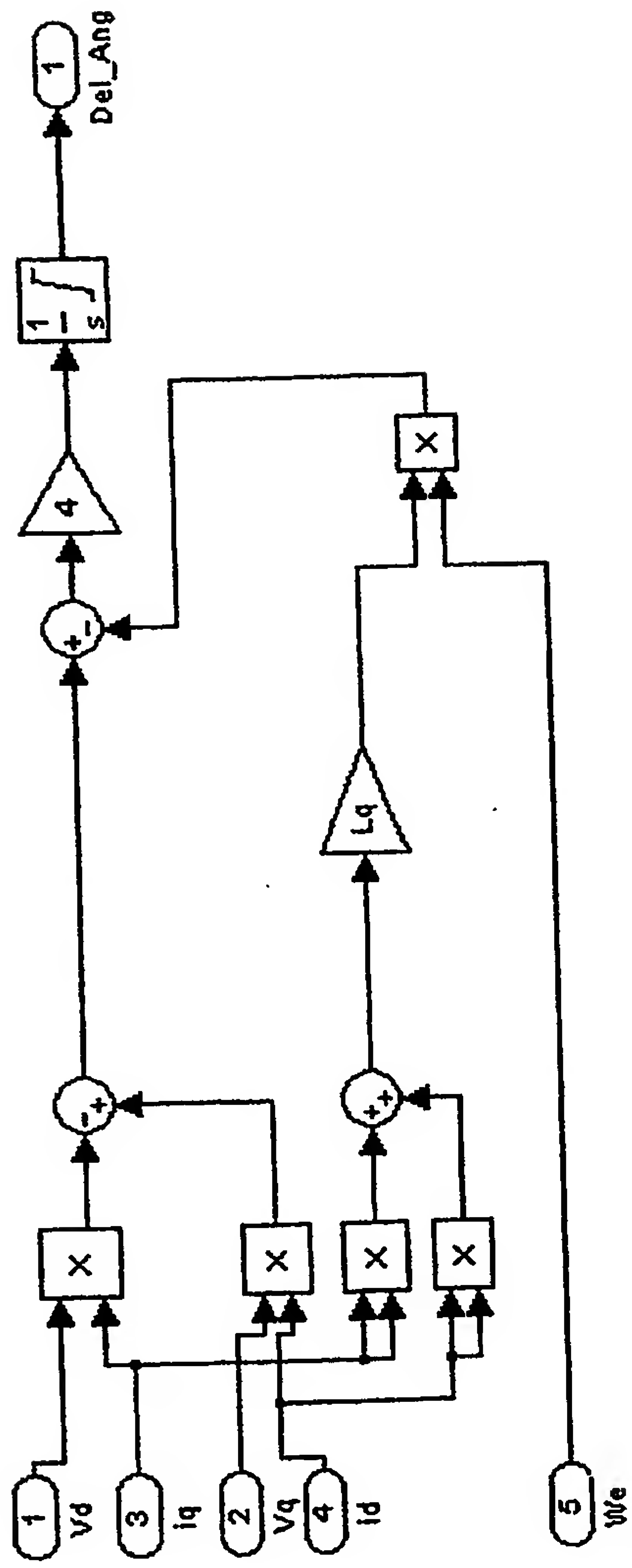
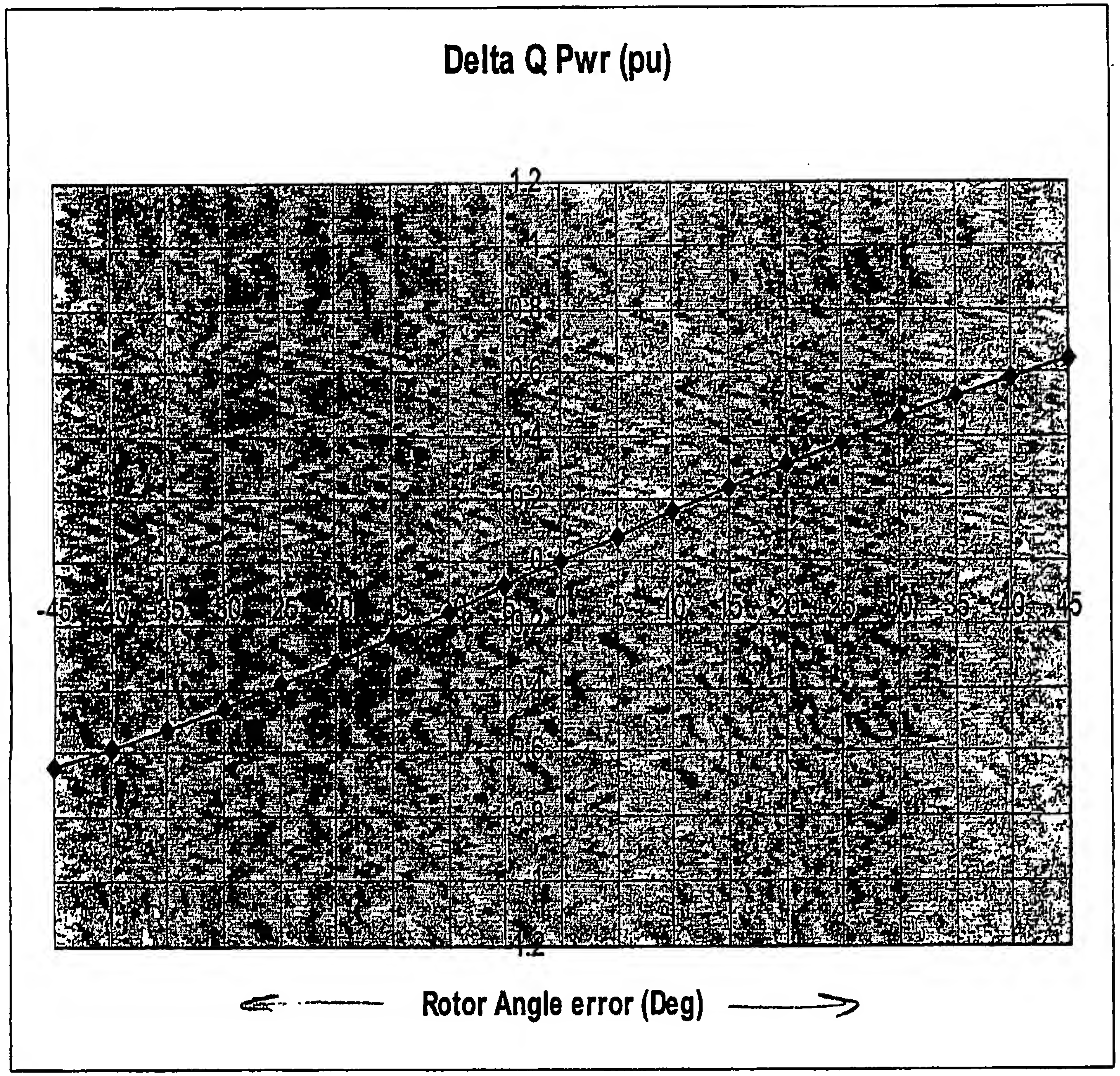


Fig. 4

Fig. 5 Reactive power error vs Rotor angle error



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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US02/36382

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : H02P 1/46, 5/28, 7/36
US CL : 318/254, 439, 700, 721
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 318/254, 439, 700, 721

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6,462,491 B1 (IIJIMA et al) 08 October 2002 (08.10.2002), see entire documnet	1-3, 5, 6, 7
X	US 6,396,229 B1 (SAKAMOTO et al) 28 May 2002 (28.05.2002), see entire documnet	1-3, 5, 6, 7
Y	US 6,005,364 A (ACARNLEY) 21 December 1999 (21.12.1999), see entire documnet	4,8
Y	US 5,272,429 A (LIPO et al) 21 December 1993 (21.12.1993), see entire document	4,8

Docket # ZTP03P01879
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Date of the actual completion of the international search
06 January 2003 (06.01.2003)

Date of mailing of the international search report
04 APR 2003

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